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A Systems Integration Framework for Interdisciplinary Black Sky Operations

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Abstract: During a large-scale "Black Sky" power outage in the continental United States, the private sector as well as federal, state, local, tribal and territorial emergency management communities will be tasked with providing support for an extended period of time and to a very large population over a large geographic region. Such an event would cause unprecedented essential service disruptions not only within the power sector, but also for transportation, water, and communications sector infrastructure, as well. Most critically, any communications systems that can operate during such an emergency will be limited in bandwidth (as compared to the communications systems that we all use every day), potentially causing an adverse effect on cross-sector coordination efforts. As a result, there is a need to pre-plan and develop, in advance of such a "Black Sky" power outage, an appropriate human and technical interoperability framework that will support the eventuality of a Black Sky event, and thereby pick out the most-critical data to be generated and shared, so as to be able to conduct restoration and emergency-management activities within the available bandwidth.

To help address the need to develop a communications system that will function during Black Sky Events, we have used a systems analysis approach to research and identify usage requirements for the purposes of command, control, coordination, and communications. Black Sky operational mission requirements were identified across multiple disciplines for the steady-state, response, and recovery phases of emergency management. Each operational requirement was cross-walked to the corresponding information requirements needed to support the activity. Black Sky operational mission requirements were categorized as fulfilling one of three mission-critical functions: Execution of Strategic Mission Priorities, Cross-Sector Planning and Coordination, or Resource Request and Acquisition. The corresponding information requirements were organized by utility of the information type: Event Characterization, Consequence Analysis, and/or Decision Support. Data elements were then aligned with each information requirement to define the most appropriate and comprehensive source of that information. Each data element was described by the relative load requirements for information transfer within a Black Sky-functional communications system.

Based on the results of this analysis, we defined the relative total load requirements for a communications system designed to fulfill the information needs of the user community during a Black Sky event. The results have been aligned to the systems analysis performed; this structure will help ensure that responders have the right information, at the right time, to effectively perform their missions and guide alignment of the information needs to the Black Sky communications system infrastructure. This analysis is the first to connect and prioritize the operational activities of the emergency management community to the technical information, data, and communications systems load for large-scale power outages.

Keywords: System architecture; Black Sky; Information Sharing; Emergency Communications

1 Introduction

Research and real-world events have shown that the existing communications system in the United States cannot be relied upon in the aftermath of a large-scale emergency, as it would likely be unavailable for use. This loss poses a tremendous problem, as the Electric Infrastructure Security (EIS) Council has demonstrated through its Black Sky exercises: the lack of effective and reliable electronic communications is one of the critical factors in the near-catastrophic severity of such events. In response to these previous findings, EIS is working to develop an emergency communications system to fill this gap for a large-scale Black Sky event triggered by natural or manmade causes.

The requirements for such an emergency communications system have previously been based on expert analysis drawn largely from a command and control system, as used by the United States military. In command and control environments, the information requirements include the situational awareness data required to understand the event as it evolves, as well as the information required to manage and perform restoration. By contrast, within the United States, the emergency management community is tasked with coordination and communications functions, while restoration activities are performed by private and public utilities. Therefore, the technical demands of an emergency communications system, as envisioned by EIS, requires an understanding of the information requirements to support coordination and communications between players, but is assumed to be limited in the requirements focused on restoration activities.

Here, we present the results of an analysis of the information requirements of an emergency communications system to support emergency response and restoration activities following a Black Sky event, as described previously by EIS. The results are organized by operational, information, and data requirements for multi-sector coordination and communications. Associated metadata were defined to support the technical specifications for an emergency communications system (ECOM), as described in a previous report [1] and to inform development of a companion software-based national recovery coordination system, or BSX, that will facilitate command, control, communications, coordination, and counter-intelligence [2].

2 Methods

The following details the systems analysis methods, coordination emphasis, operational phases, and information management methods. The overall goal of the research and analysis was to better understand usage requirements of the BSX system for the purposes of command, control, coordination and communications and to design an implementable framework that would inform workflow and load requirements.

2.1 Systems analysis approach

To identify and categorize the information requirements for an emergency communications systems for Black Sky events, we used a systems analysis approach incorporating analysis from emergency management at the federal, state, and local levels; previous analysis of the information available to these types of decision makers; and available from and within the energy sector for the steady state, response, and recovery phases of emergency management. Results from previous research and experience working in emergency management suggest that information requirements are directly tied to mission-specific operational tasks, each supported by specific data [4]. A systems-level framework was developed to define and link these operational mission requirements (tasks) to the information requirements needed to inform the operational mission, and, in turn, to the data needed to meet the information requirement.

Operational mission requirements were defined through a series of 12 regional information-sharing projects sponsored by a U.S. Department of Homeland Security research initiative known as “Virtual USA” [5, 6]. During program implementation, ~220 total mission requirements were collated from ~4,500 individuals and ~50 working groups representing over 500 state and local agencies throughout 40 states, 7 Canadian provinces, including 25 state’s National Guard, and more than 150 private sector companies and non-governmental organizations. This effort included the analysis and prioritization of strategic mission priorities by State Emergency Management Directors, Adjutants General, and other senior government officials, often resulting in a much smaller sample (i.e. less than two dozen) of operational mission requirements to support the functions of command, control, coordination, and communications across multiple jurisdictions. The researchers' understanding of operational mission requirements was refined through prior energy sector emergency management research [4], including conversations with emergency management personnel from relevant federal agencies, and on the priorities outlined in the National Response Framework and its Emergency Support Function annexes [7]. The operational mission requirements include those specific to each phase described in the National Response Framework FIOP and specific to Black Sky events, even when not previously prioritized.

Information requirements were defined based on use case analysis of the specific user groups previously referenced, defined as "essential elements of information" (EEIs) required to support a specific operational mission requirement(s). The information requirements were aligned with the National Strategy for Information Sharing & Safeguarding [8] and the Information Interoperability Framework [9]. In developing the BSX information requirements, 350+ EEIs were consulted from research of the Virtual USA program that have been refined by the Incident Management Information Sharing Sub-Committee (IMIS-SC) [10] of the White House National Security Council. Our final analysis focused on those information requirements that directly support the operational mission requirements of the target user communities in a Black Sky event, and defined based on previous analyses [4,11]. The results include information identified as needed to support operational mission requirements during events by experts in emergency management response within the energy sector.

Data requirements were defined based on a series of 350 interviews with 458 individuals across the federal interagency emergency management community and linked to corresponding information requirements, as defined above, and through the work of the IMIS-SC [10,11]. Data requirements are defined by the datasets needed to meet each information requirement. (e.g., infrastructure of concern in the impacted area, population with durable medical equipment). Each data requirement is characterized by the relative information transfer load within a Black Sky-functional communications system, as defined by the number and type of fields required for tabular data and text and the number and type of geospatial elements and metadata fields required for maps. These results define the technical specifications required to meet the information needs of the emergency management community during a Black Sky event, ensuring that responders have the right information, at the right time, to effectively perform their missions.

2.2 Emphasis on coordination

Our research and analysis builds upon the understanding that response and recovery for a Black Sky emergency, supporting the "whole of community," requires an information management [9] and communications interoperability [12] framework to serve the operational coordination and management functions of the emergency management community at federal, state, local, tribal, and territorial scales. The primary management requirement during a Black Sky event, or any other emergency, is to understand the situation, what tasks are required to mitigate losses, and the process by which the response and recovery efforts can most effectively and efficiently mitigate those losses. The primary coordination task is to determine how organizations can best work together to coordinate prioritization and delivery of services to support the needs of the "on the ground" operational response and recovery apparatus of private and public organizations, given the dependencies between the sectors and between each task of response and recovery.

This approach explicitly recognizes the roles and responsibilities of each organization and asset owner to execute their own Black Sky emergency plans within their respective chains of command, while addressing the need for national-level coordination of activities. This coordination across the emergency management community involves multiple sectors and requires macro-level coordination throughout the community within the context of command, control, coordination, and communications (C4). Notably, this approach posits that macro-level coordination may co-exist with micro-level coordination, defined as that which is managed from within an organization that may have greater tolerance for traditional C2 approaches, as typically employed by the military in theatre. Therefore, the approach proposed here to effectively manage and coordinate Black Sky emergency response and recovery includes defining clear operational mission requirements that support the functions of management and coordination, and supporting information and data requirements that serve the mission of national, regional, and local efforts. This approach is designed to support a nimble communications architecture that will provide the information needed for effective management and coordination within a "Whole of Community" effort, while relying heavily upon distributed responsibility for response and recovery activities by asset owners and locally managed organizations in widely disparate geographic regions throughout the United States.

2.3 Operational phases

The Black Sky Operational Phases (Fig. 1) were drawn directly from the FEMA Response Federal Interagency Operational Plan (FIOP). The FIOPs are built upon the concepts outlined in the National Response Framework, and serve as operational documents specifying how various Federal agencies work and interact to support national preparedness. There are five FIOPs, each describing one of the preparedness mission areas: Prevention, Protection, Mitigation, Response, and Recovery [3].

The National Response Framework and the five FIOPs articulate a comprehensive vision of how the numerous agencies comprising the preparedness community can work together using common language and operational procedures, thereby aligning their mission-specific practices with those of the overall community. In support of this integration strategy, three emergency management phases and eight sub-phases used in this document are drawn directly from the FEMA Response FIOP.

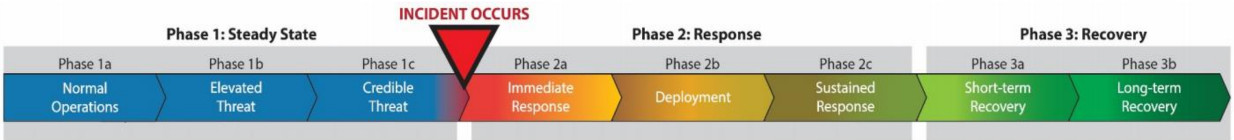

Fig. 1. Response FIOP Phases of Emergency Management.

2.4 Information management

For each Black Sky Operational Sub-Phase, a series of three information categories was provided to broadly scope and define the related operational information and data requirements. These three information categories are Event Characterization, Consequence Analysis, and Decision Support.

Event characterization models and analyses convert raw observational data into situational awareness information describing the location, timing, and/or severity of an event. Event characterization performed during a hazardous event may predict, for example, the cities or regions likely to be affected and to what degree. Event characterization may occur before, during, or following an event to support long-term planning of a hypothetical event, rapid assessment of an ongoing event, or extent validation of an event which has already occurred, respectively.

Consequence analysis incorporates infrastructure, economic, and/or population data into the extent, timing, and severity results produced via event characterization. Consequence analysis produces impact estimates for the affected areas, including, for example, economic loss, infrastructure damage, and disruptions to supply chains. During a hazardous event, consequence analysis may be performed following event characterization to estimate, for instance, the potential number of affected or displaced individuals, proportion of buildings damaged, human health effects, and/or economic consequences in the identified high-risk regions.

Decision support analysis translates the impact estimates produced by consequence analysis into actionable, mission-specific data. Decision support analysis produces estimates such as the amount of materials or number of personnel needed to support each activity. During an event, consequence analysis may predict the number of individuals likely to be affected by a hazard, and then decision support analysis may be performed to predict, for example, the number of medical professionals and supplies needed to treat those individuals. Consequence and decision support analysis have significant utility before and during an event, as they allow emergency personnel to predict and mobilize the appropriate resources before a hazardous event has reached a catastrophic level.

Furthermore, the information requirements presented detailed at a minimum the following:

- Who will use the information;
- Name of the information item;
- Description of the information item;
- Is this information item likely to be *required*, or only *desired;*
- Form the information item will take;
- Frequency of measurement or acquisition required to support the mission;
- Accuracy / quality requirements;
- Source(s) for this information item; and
- Rationale for the need / desire for this information item.

3 Results

A systems analysis approach was used to define and structure the results of our research and analysis into collections of operational, information, and data requirements for the BSX.

3.1 Systems-level overview

A relational database was constructed based on the results of the systems-level analysis of Black Sky requirements described previously (Fig. 2). The database includes three requirements tables focused on operational missions, information requirements, and the corresponding data requirements for each. Metadata attributes (bulleted lists in Fig. 2) describe each requirement's role and technical characteristics in the context of Black Sky operations, as relevant to the BSX.

Like the systems framework, the relational database is hierarchical, with operational mission requirements fed by one or more information requirements, and information requirements fed by one or more data requirements. These interconnections are specified using an associative table of keys that defined which information requirements fed each operational mission requirement and which data requirements feed each information requirement.

A set of 34 operational mission requirements, 16 information requirements, and 26 data requirements are described (see Fig. 2 and Appendices A, B, and C). The requirements were developed based on the research team's analysis and experience in supporting the function of emergency management and from Virtual USA projects, conversations and interviews with professionals in related communities of practice.

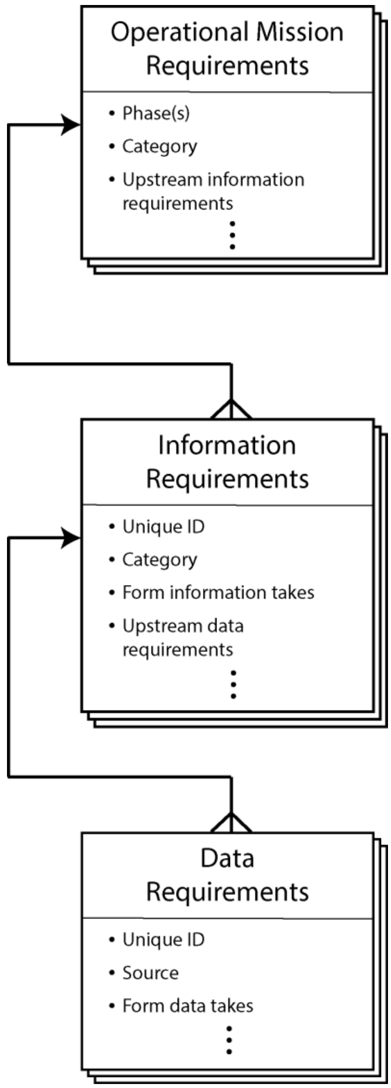

Fig. 2. Systems-level framework for Black Sky requirements

3.2 Requirements databases

Three distinct and interconnected requirements databases were developed based on the systems-level framework: operational mission requirements, information requirements, and data requirements.

3.2.1 Operational mission requirements

Operational mission requirements define phase-specific actions taken by the emergency management coordinating entity. The operational mission requirements reflect the core response and recovery activities coordinated by emergency management agencies relevant during a Black Sky event. They are focused on actions required to facilitate the overall progress of the steady state, response and recovery phases by ensuring effective and timely coordination of information and cross-sector activities. Operational mission requirements are focused on emergency operations and goals overall without specifying individual, organization-level tasks. For example, the operational mission requirement "Transport resources into impacted area" defines the requirement to deliver food, water, and other mass care resources to impacted areas, without stating which agencies or groups are responsible for the task.

An example operational mission requirement is provided in Table 1. The complete operational mission requirements table is provided in Appendix A.

Phase(s)	Operational Mission Requirements	Category	Description	Upstream information Requirements
Deployment	Transport resources into impacted area	Resource Request and Acquisition	Transport the personnel, meals, water, utility repair equipment, and other resources that are needed for the response into the impacted areas, using the most direct functional ingress routes from the resource sources.	I9, I10, I11, I15

Table 1. Example operational mission requirement and metadata attributes.

3.2.2 Information requirements

Each operational mission requirement is linked to one or more information requirements that defines the information needed by the coordinating entity to effectively carry out operational mission requirements. Information requirements are based on the information that are both available and necessary to guide each operational mission requirement. Most operational mission requirements are supported by multiple information requirements. Information requirements represent the integration of data sources owned by a range of agencies and organizations to provide essential context for response and recovery operations beyond those provided by the individual data elements. For example, the information requirement "Transportation ingress / egress status" synthesized transportation infrastructure status, power outage estimates, fuel availability and supply requirements, and the active hazard event data to provide a map of current transportation status relative to the active hazard footprint. This collated information product can be used to directly support operational mission requirements that concerned moving in and out of the impacted area, such as "Transport resources into impacted area".

An example information requirement is provided in Table 2. The complete information requirements table is provided in Appendix B.

Unique ID	Information requirement	Category	Information format	Upstream data requirements

I9	Transportation ingress / egress status	Consequence analysis	Map (first layer): For each state, the location of each transportation node/road is mapped, with icon or line color indicating status (open, restricted, closed), and timestamp Map (second layer): Contours defining the geographic extent of each severity level of the hazard, using the appropriate hazard-relevant scale (hurricane wind categories, earthquake shaking intensities, etc.), and timestamp Table: Transportation node name, type (e.g., bridge, road, port), name, service area (state, county), address, lat/long, status (open, restricted, closed), estimated date and time of re-opening, and timestamp	D0, D1, D2, D6, D11, D16

Table 2. Example information requirement and metadata attributes

3.2.3 Data requirements

Each information requirement is linked to one or more data requirements that defined the specific datasets that needed to be collected and available during Black Sky operations to support response and recovery decision-making. The data requirements are focused on individual datasets that need to be stored and made available on an ECOM and BSX platform to support operational mission requirements. Data requirements are based on the specific, granular data elements needed to create the product described by each information requirement. The relative load requirements for the ECOM and BSX platform are defined by the data fields needed for each data requirement. Data requirements are described as tables, maps, or both, with each required table column and map feature specified. For example, the data requirement “Operational status of impacted transportation critical infrastructure” is linked to several key information requirements and is described both as a table with 9 data columns per impacted infrastructure node and as a map with 3 map features per impacted infrastructure node. The custodial owner of the dataset serving as the source for the data requirement was also specified. Custodial owners are identified, including agencies at all levels of government and in all sectors, private organizations, and industry. For both data requirements and information requirements, the voice communications capacity needed to ensure the data can be collected and discussed if electronic messaging and file transfer are impossible is also specified (e.g., point-to-point, teleconference, live video). Several data requirements identified are dynamic, meaning they need to be refreshed regularly during Black Sky operations to be kept current and relevant. Others are static, meaning they do not need to be refreshed.

An example data requirement is provided in Table 3. The complete data requirements table is provided in Appendix C.

Unique ID	Data requirement	Source	Data format
D6	Operational status of impacted transportation critical infrastructure	General transportation status data are collated in the DOT Map (DOTMAP). Airport status data are sourced from the FAA. Port status data are sourced from the USCG Homeport platform. Rail status data are sourced from DOT and private rail providers. During Black Sky events: Same, but likely to be delayed if relevant agencies' facilities lose continuity of operations from outages. Initial transportation infrastructure status reports may need to be exchanged via phone call. Custodial owner of data: DOT, FAA, USCG	Table: Transportation node name, type (e.g., bridge, road, port), name, service area (state, county), address, lat/long, status (open, restricted, closed), estimated date and time of re-opening, and timestamp Map: For each state, the location of each transportation node/road is mapped, with icon or line color indicating status (open, restricted, closed), and timestamp

Table 3. Example data requirement and metadata attributes

3.3 Aligning operational missions with information requirements

A fully functional ECOM and BSX platform must successfully include, integrate, and synthesize an array of data requirements to support operational mission requirements. The systems-level framework characterizes complex interconnections and interdependencies between all three types of requirements aligned in the hierarchy. Fig. 3 illustrates these interdependencies for two critical operational mission requirements. For example, the data requirement “Active hazard event data” is needed to support both operational mission requirements, and both would be affected by any disruption to this data requirement, such as a failure to collect or update the data during Black Sky operations.

The complexity of interconnections seen even in the relatively small subset of examples in Fig. 3 suggests that a robust systems-level framework is needed to ensure efficient implementation of data requirements in the ECOM and BSX platform. The framework allows data requirements to be directly mapped to the operational mission requirements they support such that only data requirements necessary during Black Sky operations are included. Adopting such a systems-level framework in the implementation of an ECOM and BSX platform would ensure that all data required for operations are provided by the platform.

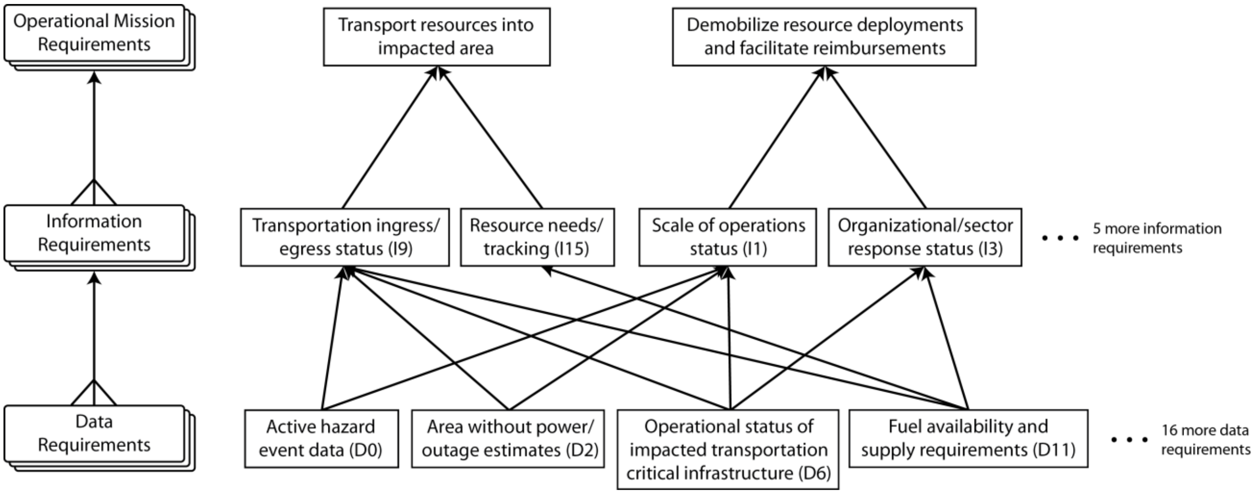

Fig. 3. Alignment of systems-level requirements framework to examples. Not all supporting information requirements and data requirements are shown.

4 Conclusion

Here, we describe a systems-level ontological framework to list and characterize Black Sky requirements. Specific operational mission requirements, information requirements, and data requirements are defined within the framework, including the hierarchical relationships between them. Data requirements are characterized by their relative load requirements for information transfer in order to support future work in estimating the absolute disk space and bandwidth requirements for the ECOM and BSX platforms.

4.1 Incorporating data into the platform

In developing the ECOM and BSX platform, the specific data and information requirements defined here need to be incorporated to ensure that the necessary actionable information is available to the decision-makers and groups tasked with meeting operational mission requirements. The systems-level framework and database developed links specific data sources to operational mission requirements to ensure that data required to support the response and recovery would be built into an ECOM and BSX platform. This approach complements emergency response plans, which set forth agency- and organization-level emergency operations activities in pre-scripted mission assignments and other forms. The data and information requirements defined are highly specific to clarify the source and format of actionable information to drive response and recovery activities. The operational mission requirements are flexible, emphasizing the task that must be completed over the group that should be responsible for it, and primarily serving to motivate the incorporation of specific data in the platform.

4.2 Providing information in the proper form

As the ECOM and BSX platform is developed, it will need to be designed to incorporate the information requirements and formats required to support operational mission requirements. By tailoring the data and information provided to operational missions, the platform will be much more likely to meet the needs of the end users in the emergency management community. Likewise, the information requirements will need to be presented in a format that is immediately useful to the user community and clearly addresses specific decisions in response and recovery operations.

4.3 Importance of adopting a systems-level framework

The complex interdependencies between data requirements and operational mission requirements suggests that a systems-level framework should be used to guide the implementation of the ECOM and BSX framework, as was described here. Most information requirements rely on the successful inclusion, integration, and synthesis of not just one dataset but several to effectively support Black Sky operational mission requirements. This finding highlighted the utility of clearly articulating the specific data elements that comprise each data requirement and the connections between all system components from the data level to the operational action level.

4.4 Ensuring access to Black Sky-relevant datasets

As the ECOM and BSX platform is developed and implemented, it will be critical to work with the custodial owners of data sources. Expectations of what data will be provided (as defined in the “Form” metadata attribute of the relational database) and when will need to be defined in advance to ensure optimal function of the platform. A diverse range of custodial owners for data sources to meet data requirements included Federal agencies such as FEMA and DOE, State agencies, and private sector or industry owners. Establishing close relationships with these groups during platform development will ensure that data are available to the platform when needed during Black Sky operations; this coordination is especially important for dynamic datasets that must be continually updated during the event.

Once the ECOM and BSX platform is implemented, the included data requirements should be regularly updated and refreshed to ensure that newly developed or refreshed datasets are kept current. For example, static datasets describing the population with durable medical equipment are updated on a regular schedule during steady-state. The ECOM and BSX platforms must be loaded with or able to access the most recent versions of such datasets to ensure Black Sky operations are based on the most recent data. Similarly, plans to access updates to dynamic datasets during the event should be pre-established and tested.

4.5 Technical specifications for the platform

Additional work building on these results is required to determine the absolute data transfer load that the ECOM and BSX platform must be designed to accommodate, including choice of information technology solutions. This work lays the foundation for determining the technical specifications for the platform by defining the relative data transfer load for each data requirement (i.e., the number of and type of data fields needed per data requirement). However, these results do not address information technology and device considerations, such as the choice of operating system, geographic information system (GIS) application, security software, and hardware setup, which will impact the absolute number of bytes that the system must handle. Once these considerations have been addressed, the results of this work can be used to directly support disk space and bandwidth requirement calculations. It will be essential to optimize requirements to ensure efficiency during a resource-limited Black Sky scenario.

The voice communications bandwidth requirements for the platform will also require careful consideration. In addition to supporting the use of data during Black Sky operations, the platform will be required to support robust voice communications between parties involved in the response and recovery. The relative voice communications bandwidth requirements associated with each data requirement and each information requirement have been defined here, but additional analysis will be required to estimate bandwidth requirements based on the expected frequency of point-to-point and teleconference calls, the number of concurrent calls expected, the average length of calls, and the data transfer per unit time required for each type of call.

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Appendix A. Operational mission requirements table
Appendix A is included as a separate attachment.

Appendix B. Information requirements table
Appendix B is included as a separate attachment.

Appendix C. Data requirements table
Appendix C is included as a separate attachment.

Appendix D. About the authors

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